SCHOOL OF CIVIL ENGINEERING

JOINT HIGHWAY RESEARCH PROJECT

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TREATMENT OF SANITARY WASTES AT INTERSTATE REST AREAS

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PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Interim Report

PHASE III, TREATMENT OF SANITARY WASTES AT INTERSTATE REST AREAS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

June 1, 1978
Revised July 1979
Project: C-36-67F

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

File: 9-11-6

The attached draft Report is an Interim one on the HPR Part II Research Study titled "Treatment of Sanitary Wastes at Interstate Rest Areas". The Report covers the period of participation by JHRP personnel in the design and construction - JHRP participation in these periods was only advisory - and more importantly in the testing and evaluation of the two experimental systems from beginning of operation in late 1975 through December 1977. The Report has been authored by Dr. James E. Etzel, principal investigator on the research.

The numerous problems and difficulties together with the potential of both systems - recycled effluent and once-through systems - which have occurred during the two years are reviewed. Solutions to them are of course discussed and the capabilities and advantages of the systems are shown from tests made when the systems were operating satisfactorily.

The research has continued since December 1977 and from the experience and evaluation which have resulted, it now appears that with some modifications - some already made and others in progress or planned for an early date - that the systems will be successful and the research objectives achieved. A Proposal to continue the evaluation through December 31, 1979, is currently being processed.

This Report is submitted for review and comment and for acceptance as partial fulfillment of the objectives of the Study. Following presentation to the JHRP Board, it will be forwarded for review, comment and similar acceptance by ISHC and FHWA.

Respectfully submitted,

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Interim Report

Phase III

TREATMENT OF SANITARY WASTES AT INTERSTATE REST AREAS

by

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Project No.: C-36-67F

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16. Abstract
This Interim Report is for the period of Phase III of the research through December 1977. Phase III involves the testing, analysis and evaluation of experimental treatment facilities installed in Interstate Rest Areas on I-65 near Thorntown, Indiana. Two systems were built, one - for southbound traffic on I-65 - used recycled effluent to flush the toilets. The other did not utilize recycled water. Both systems utilize a waste disposal system based on aerobic principles and all parts of each system are within the rest area building.

This Report records the problems and difficulties together with how they were handled from initiation of design of the facilities through construction and two years of operation.

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INTRODUCTION

The need to service a mobile public at highway rest areas, picnic grounds, and campgrounds has created significant problems in regard to the treatment and disposal of sanitary wastes. Many attempts by various state and federal agencies have been made to handle this problem, but no good answer has really been found. The problems basically arise from the sporadic use of the facilities by the public and the remoteness of these areas from streams capable of assimilating the treated effluent. The plants traditionally used at rest areas have either been unreliable, required very large land areas, have been very costly, or have required special expertise which state highway agencies usually do not have. Conventional methods of treatment have included septic tanks followed by percolation fields or sand filters, privies, oxidation ponds, and extended aeration plants. A few types of physical chemical treatment plants for use at highway reststops have been developed in the past few years.

This project is essentially the last phase of a three phased study undertaken by Purdue University and the Indiana State Highway Commission. Phase I dealt with the wastewater treatment plant development and design parameters pertaining to it. Phase 2 involved the determination of anticipated loading factors at reststops.

This phase of the research, Phase 3, involves the testing, analysis, and evaluation of the actual Phase 1 treatment plant at a highway reststop. Two systems were tested, both on opposite lanes of Interstate 65 between Lafayette, Indiana and Indianapolis, Indiana. One system used recycled effluent to flush the toilets. The other system was similar, only it did not utilize recycled water. Each system was divided into two sides, one serving the men's restroom and one serving the women's restroom.

Background of Rest Areas - Sizing Wastewater Facilities

As defined by the Federal Highway Administration (1), a rest area is a roadside area separated from the main roadway with provisions for stopping and resting for short periods of time with parking facilities for three or more cars. Presently, there are over 7600 rest parks being operated and maintained by state highway departments on interstate, primary, and secondary highways throughout the United States (2). They are usually located on interstate highways about a half hour distance from each other. Spacing is not dependent on average daily traffic (ADT) or population density. Of the 7600 rest parks, only 16 percent have modern toilet facilities. Privies are used in 23 percent of the rest areas while the remaining 61 percent have no restroom facilities. Along interstate highways, 60 percent of rest areas provide modern flush toilets.

Problems of Wastewater Treatment Plant Design - Sizing

Sizing of wastewater facilities is quite simple and is done on the basis of average daily traffic (ADT) (3). ADT's are usually projected 20 years into the future and this number is the basis for design. The number and types of vehicles which enter a given rest area is based upon an assumed fraction of ADT. Using the average number of occupants per vehicle, the facilities are sized to accommodate the expected summer time usage. Once an estimate of the projected number of users during the maximum use day is made, the sewage treatment plant is based on an estimated water consumption figure and BOD production per capita per day.

The numbers being used in this design are the under-lying cause for the first problems of design of treatment facilities (2)(4)(5)(6). There seems to be no unified basis of design. Another problem directly related to design is that forecast populations may be considerably higher than those anticipated when the reststop first opens (2). This often results in operating problems for sewage treatment plants.

The most unique feature or problems of rest areas and comfort stations is the variable loading which they receive from a highly mobile case of a municipality, but by a fraction of the traffic using the roadway adjacent to the rest area. Usage is extremely dependent upon day of the week, the month, time of day, location, and weather. Concentration of different parameters in sewage is found to be extremely variable.

As a result of the problems described, investigators have attempted to arrive at better design parameters and characterize wastewater from reststopes. The general result of these studies have shown that sewage from rest areas should lend itself to conventional biological sewage treatment systems.

It is agreed by several investigators (2)(4)(5)(6)(7)(8) that ammonia concentrations in reststop sewage are equivalent to those in a strong domestic waste. Essentially, there is no grease or scum materials. Wastewater from rest parks contains SS and BOD equivalent in concentration to a weak to average domestic waste. The COD to BOD ratio is higher than in normal domestic wastewater because of the high paper content. Phosphate concentration corresponds to that of a weak domestic sewage. Table I shows the results of these investigations.

There is perhaps less agreement among investigators on water consumption at rest areas than any other parameter. It is difficult to determine whether these differences are regional or due to the method of obtaining an estimate. Etzel, et al, and Pffeffer (4)(7) recommended 5 gallons per capita per day for design. Sylvester and Seabloom (8) agreed with the 3.5 gallons per capita per day figure used by the Washington

TABLE 1

RESTSTOP WASTEWATER CHARACTERISTICS

State	Ref No		BOD_5 mg/l	COD mg/l	SS mg/l	N mg/l	P mg/l	pH mg/l
New Hampshire	5	Max	330	480	624	131[a]	11[b]	8.4
		Min	90	197	165	8.4	1.35	6.4
		Avg	203	330	208	63	7.2	7.2
Florida	5	Max	300	440	530	181[a]	57[b]	8.6
		Min	140	216	28	20	5.5	6.8
		Avg	180	342	186	70	21	7.4
Tennessee	5	Max	223	885	310	173[a]	41[b]	8.7
		Min	65	160	16	60	9.5	7.1
		Avg	158	362	124	96	24	7.7
Indiana	4	Max	780	2125	800			8.5
		Min	4	34	4			6.5
		Avg	30-192	81-639	21-297			7.5-8.0
Illinois	7	Max						
		Min						
		Avg.	169		230			
Iowa	5	Max	561	787	652	362[a]	20.3[b]	8.5
		Min	59	140	38	15	3.6	7.1
		Avg	210	383	224	106	10	7.9
Iowa	7	Max						
		Min						
		Avg	110-150		56-92			
Colorado	5	Max	156	507	504	102[a]	22[b]	8.3
		Min	23	145	72	4.5	3.5	7.8
		Avg	78	302	208	53	12.4	8.0
Washington	8	Max	404	478	196	201[c]	41[b]	8.8
		Min	132	355	138	98	23	7.6
		Avg	165	405	165	140	29	8.3

a = Measured as Total N   b = Measured as Total P
c = Measured as Total Kietdahl Nitrogon

Highway Commission. On the other hand, Zaltzman (5), on the basis of studies of five different reststops spread throughout the country, found average wastewater production figures to be 4.25 to 5.75 gallons per vehicle. In a few cases, water consumption was slightly higher and ranged from 4.25 to 6.5 gallons per vehicle. This can be compared to the "1968 Rest Area Usage Summary" (1) figure of 7.6 gallons of water per vehicle, measured during the summer months.

At reststops where the effluent is reused for toilet flushing, Anderson (9) determined that the upper limit for water usage was a quarter of a gallon per user. Compared to the previous consumption figures quoted, this represents a significant amount of water which can be saved by recycling water back into the toilets.

Seasonal patterns for use of rest parks are well established in most cases. Average daily traffic (ADT) is usually lowest in December and January and rises to a peak in July and August. However, the degree in variability is not the same at different rest areas. In Illinois, the ADT in January and February was found to be 70 to 75 percent of Annual ADT (7). However, in July and August, the ADT was 130 to 135 percent of the Annual ADT. Thus, there was found to be an 80 percent increase in use during the summer. In Washington, seasonal use variation was even more dramatic (8). At one rest area, use ranged from a low day of 100 visitors in January to 2,740 visitors on a peak day in August. Average number of visitors during the year was 1,000 per day. Generally, the minimum daily summer use was half of the yearly average, while normal summer time use was twice the average.

Week to week variations in traffic using reststops and recreational facilities are minor except during holiday periods. On the other hand, variations during the week are notable, especially during holiday periods.

Average traffic on Fridays in Illinois was found to be consistently 115 to 120 percent of the average daily traffic (7). At on Army Corps of Engineers campground in Mississippi, average use on Saturdays and Sundays during the summer was 2 to 3 times the average use during the week (6). At other Army Corps of Engineer campgrounds overseen by the St. Louis District Office, summer weekend use was reported as being 100 percent greater than during the week. (10).

Hourly variations in flow are even more profound. Zaltzman (5) determined that 67 percent of visitors used reststop facilities over an eight hour period. Pfeffer (7) reported that hourly water consumption varied from 20 to 200 percent of the average daily flow during the period analyzed.

Another very important parameter in design is being able to accurately estimate the percentage of ADT which will use a rest area. Zaltzman (5), in studies of rest areas in nine different locations during a 32 hour period, found that 5 to 14 percent of ADT stopped at a rest station. He concluded that there are fundamental regional differences in use of a rest park.

In view of different values of parameters quoted by investigators, Francinques, et al., (2) perhaps has the best, although maybe not the most practical approach in all cases. He recommends that when a reststop sewage treatment plant is designed, parameters should be base on actual data of another reststop in the near proximity of the proposed project. If no data is available, he suggested that figures from the studies cited in his survey be used (4)(5)(7)(8). Data selected should be from reststops where conditions are similar to those in the project area. The actual calculations used in design of the two prototype systems used in this research are attached as an Appendix of this report. In general the data used was a composite of many factors gathered by the State Highway Department.

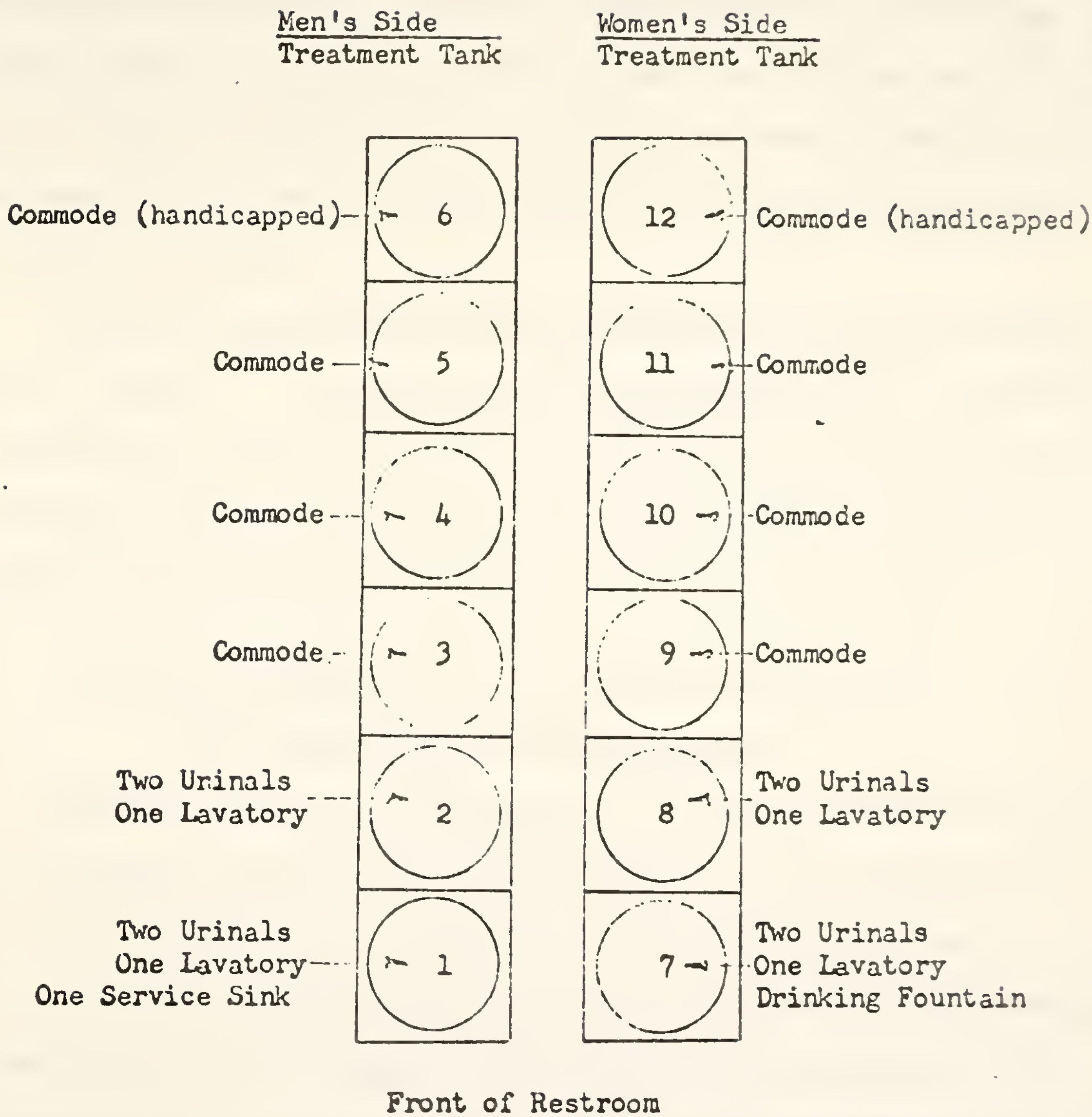
DESCRIPTION OF PROTOTYPE UNITS

The prototype units were constructed through funds from Purdue University, Indiana State Highway Commission, and Department of Transportation - Federal Highway Administration. In both restrooms, the sewage treatment system was small enough that it was possible to locate the unit within the confines of the building. Thus, the plant was not subject to wide fluctuations in temperature and climatic conditions.

Each restroom contained eight commodes and eight urinals or 16 fixtures in all. These were equally distributed between the men's and women's sides of the restroom.

At both reststops, the contents of the toilet or urinal was flushed directly into a nylon filter bag. Each commode was served by one filter bag while two urinals and two lavatories were served by a single bag. Six filter bags served the men's side and six bags served the women's side. The distribution of flows is illustrated in Figure 1. Also, the bags in Figure 1 are numbered to designate the nomenclature used in this report for identification.

The actual treatment system at both the recycle and once through system were identical in that the filter bags, aeration devices, and sewage influent flow patterns were essentially the same. The recycle system utilized a more complicated flow scheme. The effluent first flowed



Notes:

1. Prefix of S in front of bag number designates southbound lane.
2. Prefix of N in front of bag number designates northbound lane.

FIGURE 1. Sewage Flow Pattern in Restrooms and Nomenclature Used For Identifying Bags.

through a carbon contactor to remove color. A carbon contactor was located just outside the bag. From here, treated effluent went directly to a central holding sump. Constant pressure pumps pumped the water, on demand, through a surge tank and Cuno filters back into the toilets. The recycle system was provided with a tile field to provide absorption for any recycled water which escaped through the effluent overflow pipes provided in each tank.

The once through treatment plant incorporated a different effluent flow pattern from that used in the recycled plant. In addition, chlorination was provided for the effluent which then went directly to a stream. Schematic flow diagrams of both recycle and once through systems are shown in Figures 2 and 3.

Detailed Description of Plant Components Common to Both Recycle and Once Through Systems

Each of the concrete treatment tanks or units, which contained the six filter bags, measured 7'-2" deep from floor level to the bottom of the tank. Total length was 16.5 feet while the width was 5 feet.

The tank was further partitioned into six equally sized compartments, 2'-9" by 5'-0" by 7'-2" deep. These divisions were separated by 1/4" steel plates. An attempt was made to seal the edges between the steel plates and the wall of the tank. However, in no case could a perfectly watertight seal be maintained. Each steel plate had a small gate cut out to allow water flow between the compartments and the effluent pipe. These gates were about 4 inches wide and were submerged about 2 inches when the tank was full. The gates were built so that a small steel plate could be inserted for the purpose of isolating compartments in the tank.

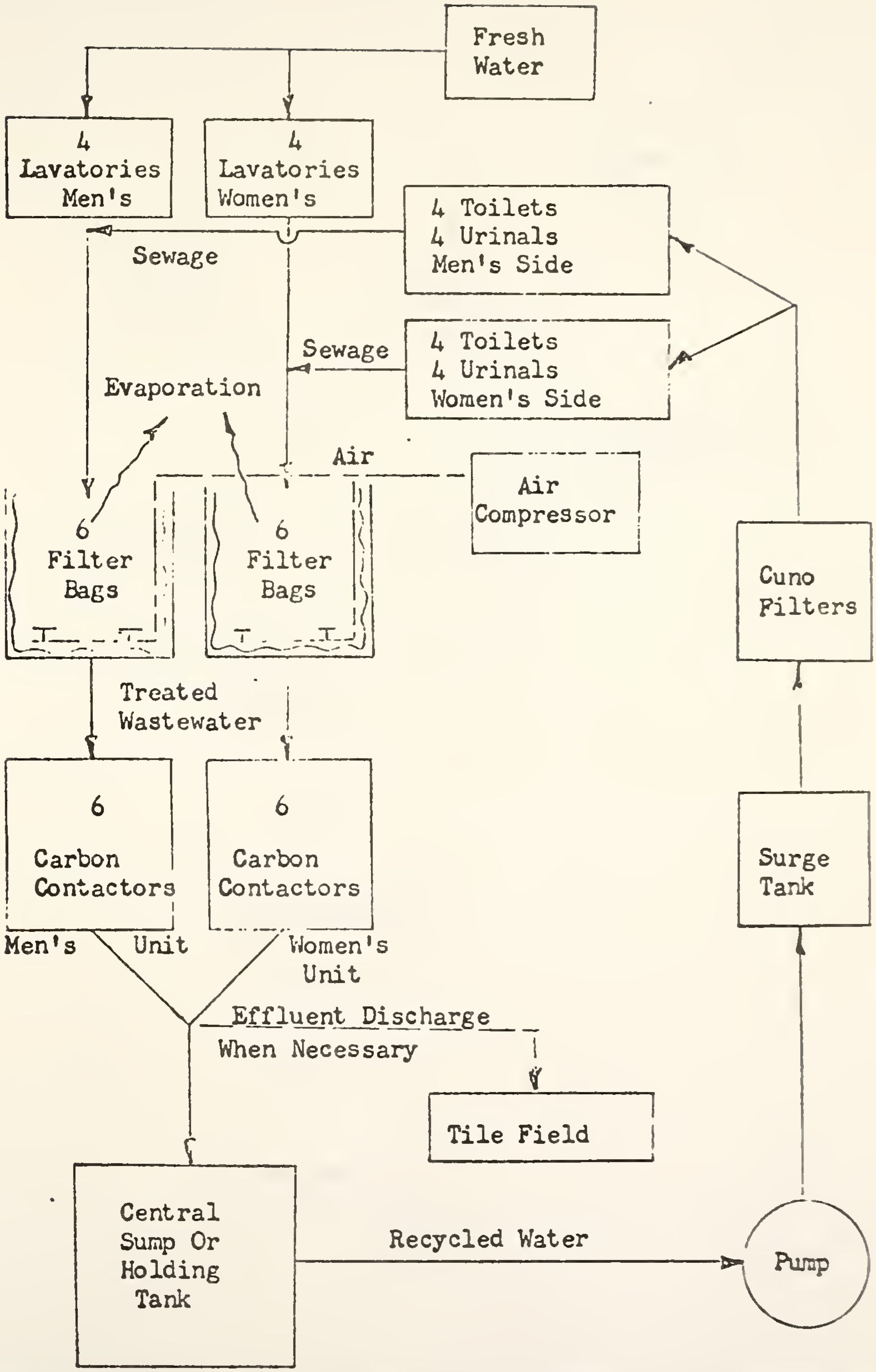


FIGURE 2. Flow Schematic of Recycle System - South Bound Lane of I-65.

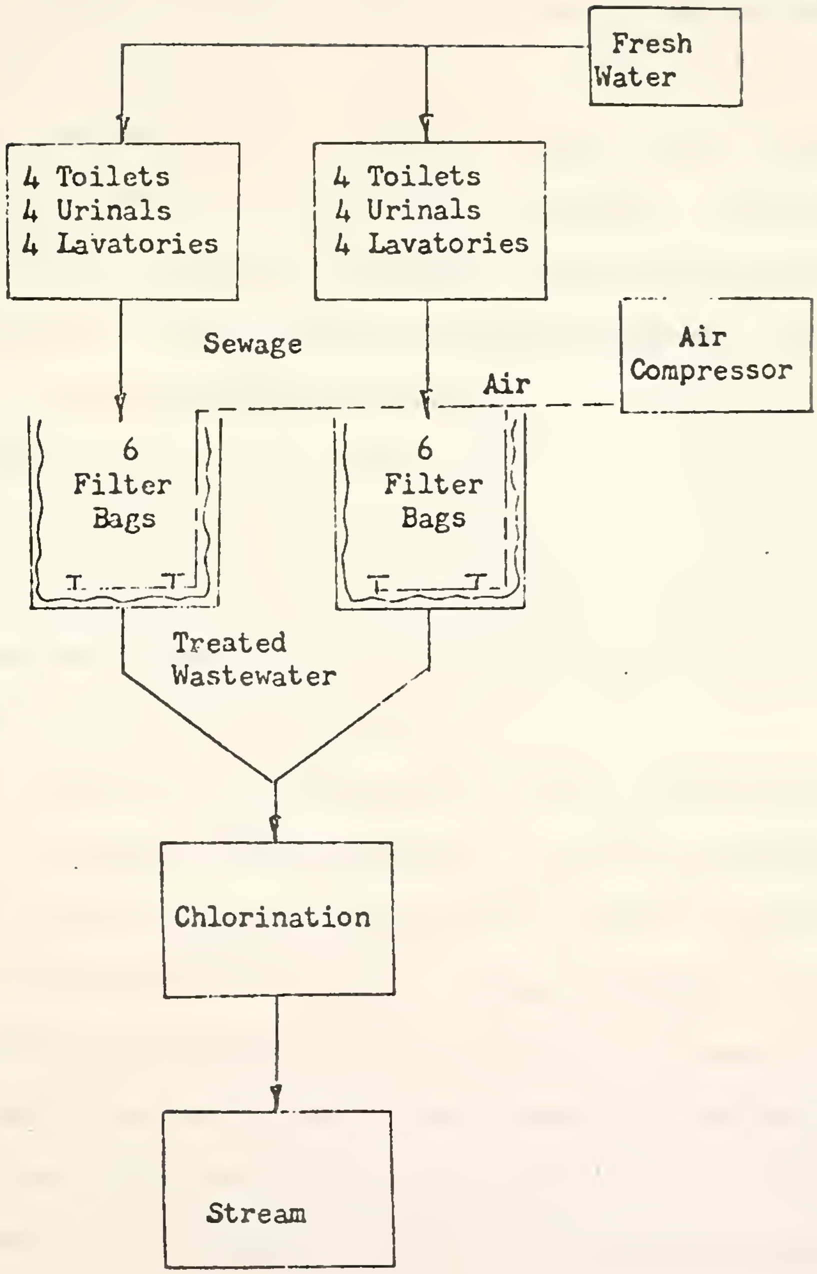


FIGURE 3. Flow Schematic of Once Through System - North Bound Lane of I-65.

The purpose of the partitions was to make it possible to pump down the level in one compartment without affecting the water level in any of the other compartments. Thus, it would be possible to keep most of the restroom open to the public while repair work was being done inside one compartment.

Effluent overflow pipes, 4 inches in diameter, were placed in each tank a foot lower than the top of the tank. Therefore, total volume of water in each tank, not allowing for head losses through the bags, was about 3800 gallons. Effluent pipes were placed at opposite ends of the tank and were positioned insuch a way that the end of the pipes were parallel with the surface of the water. On the recycle system, these effluent pipes served no purpose other than allowing the passage of recycled water outside the tanks if the wastes from the lavatories and drinking fountains (supplied with non-recycled water) exceeded the water lost from the unit through evaporation.

A filter bag was placed inside each of the six compartments. Configuration of the bags is shown in Figure 4. An actual photograph of Bags S-4, S-5, and S-6 on the recycle system is shown in Fugure 5. The filter bag was supported by a 2" by 4", 11 gauge galvanized steel wire mesh frame shaped into the configuration shown in the figure. After the welded wire basket had been shaped to the correct size and configuration, all surfaces were primed and coated with a two component, catalyzed polyamide cured coal tar epoxy coating to a dry film thickness of 16 to 20 mils.

The filter bag apparatus was slightly modified from Cho's experimental bag. (11) Cho's setup for batch feeding was circular with the

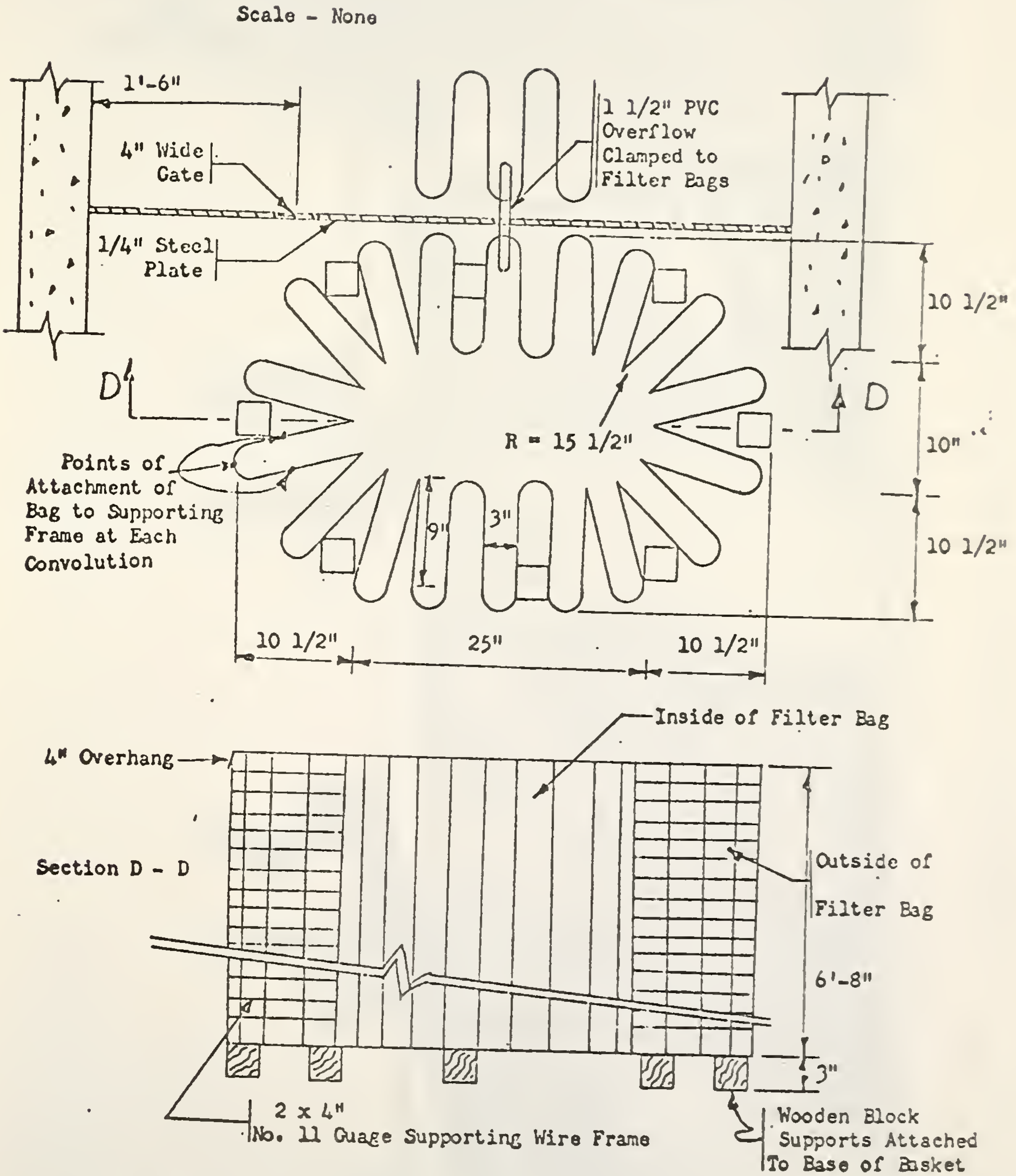


FIGURE 4. Configuration of Filter Bag.

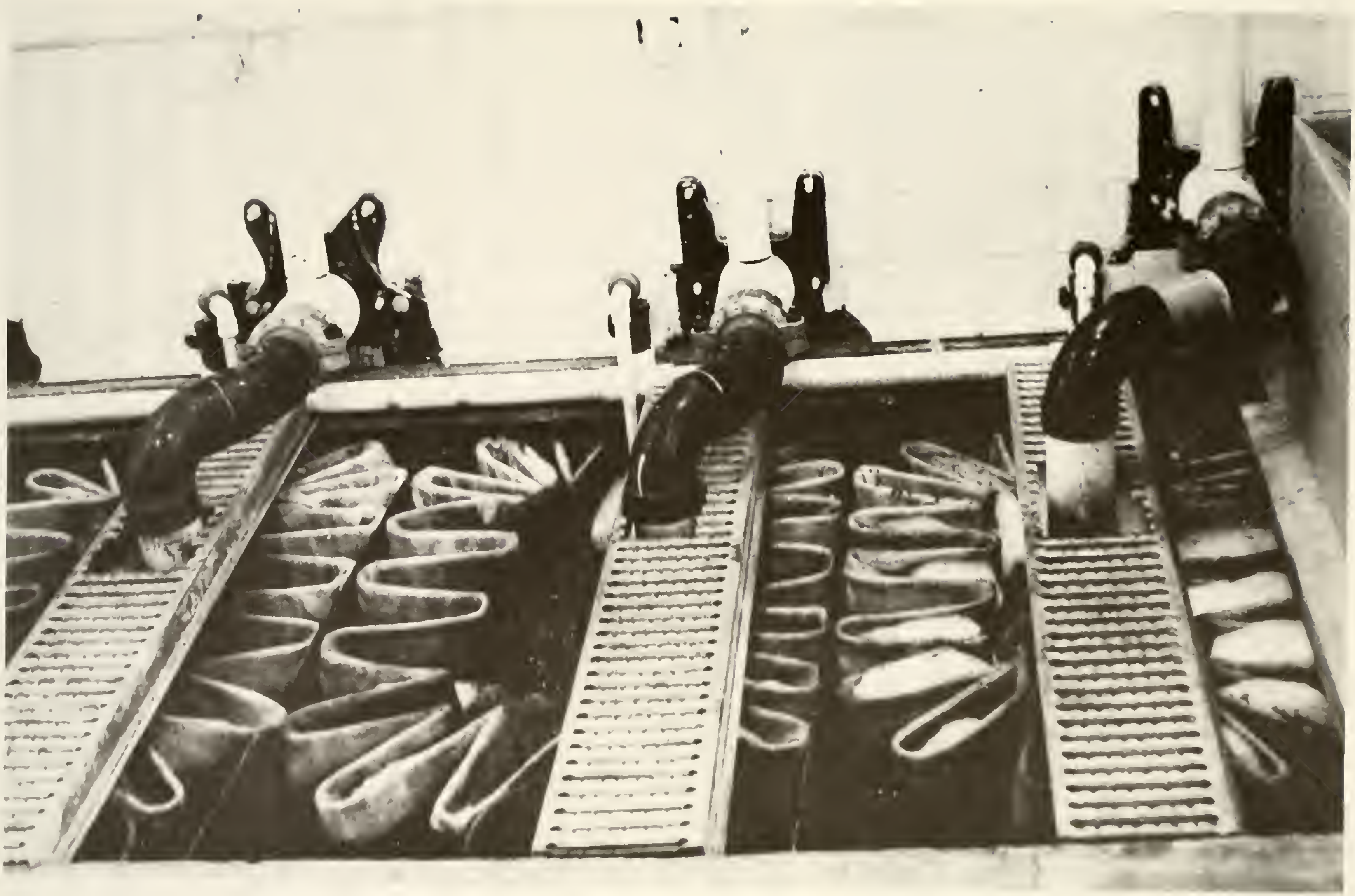


Figure 5   Photograph Showing Bags S-4, S-5, and S-6 on the Recycle System
(Photo taken by Lafayette Journal and Courier)

perimeter of the bag in a sawtooth arrangement to increase surface area. The most notable difference was that Cho used vinyl coated wire to support his bag and in this project, a galvanized steel, tar epoxy coated wire frame was used. The significance of this difference will be explained later in this report.

The filter bag material consisted of nylon with two fluffy fabric layers attached to each side of a center fabric mesh. Cho (11), in previous work on the filter bag, concluded that a nylon cloth performed the best when tested against two other fabrics. The nylon cloth (Merchandise No. PO 7034, GAF Corporation, Industrial Products Division) had a pore size of 100 microns and a nominal thickness of .065 inches.

When the filter bags were initially made, a wooden form was constructed. The wire frame was bent around this form into the configuration shown in Figure 4. A bottom supporting frame was attached, the wire was coated with epoxy, and the necessary welding was performed to make a cage. The cloth bags, which were previously machine sewed in order that they would conform to the confines of the baskets, were inserted in each basket and tied to the supporting framework with 6 pound nylon monofilament fishing line. According to specifications, the nylon bag was supposed to be attached to the frame at a 6 inch center to center maximum at the points indicated in Figure 4 on each convolution of the bag. However, later on in the test period, it was found that only the ends of the convolution had been tied at an 8 inch separation.

Each bag contained an air diffuser to thoroughly mix the bag contents and provide enough oxygen to the microorganisms. Each unit consisted of two "Activator" no clog diffuser heads (Model D12 Pollution Control Inc., Cincinatti, Ohio) mounted on 6 inch centers. Air was blown through 1/16" diameter holes distributed near the perimeter and on the bottom of the diffuser heads. Each aerator unit inside a bag was rated at 3 cfm.

At each restroom, air was supplied by two electric blowers, also part of the "Activator" aeration system (Pollution Control, Inc., Cincinatti, Ohio). Each blower was designed to deliver 40 cfm when discharging against a pressure of 4 psi. Blowers were rated at 3 H.P. and ran at approximately 1460 to 1850 rpm. The electrical control panel contained a switch to automatically alternate the blowers every 12 hours.

The blower discharged air into a two inch PVC supply line. Two 2 inch PVC header pipes branched out from the main supply line to serve the women's and men's treatment systems. The headers were located at the intersection of the utility room wall and the top of the tanks. PVC feeder lines, 3/4 inch in diameter, branched off from the headers and ran down the inside of each of the bags. Valves were placed on each of the feeders so that distribution of air to each bag could be controlled. The air header line, feeder pipes, and valves can be seen in Figure 5.

Nine inches of freeboard were allowed between the top of the bags and the elevation of the overflow pipe. Without the wooden blocks underneath the bags, shown in Figure 4, only 6 inches of freeboard would have been provided. This is mentioned because in some cases, these wooden blocks did not stay underneath the bags.

According to Indiana State Highway Commission plans and specifications, (12) a 1 1/2 inch pipe was placed between adjoining bags to relieve possible hydraulic overloading or failure of filtering capacity in a single bag. The invert elevation of this emergency overflow pipe was approximately 3 inches above the effluent overflow pipe elevation. To insert the pipes, a hole had to be cut into an appropriate place on the filter bag. The bag was then to be firmly clamped to the pipe so that no openings occurred between the bag and the outside of the overflow pipe.

The drain pipe from the lavatories and the utility sink also had to be inserted through the walls of the bag. The pipe from the lavatories was two inch PVC while the pipe from the service sink was three inch PVC. According to plans and specifications, an X cut was made into the bag to accommodate the drainpipes from the lavatories and utility sink. A corrosion resistant clamp was then used to seal the nylon around the pipe.

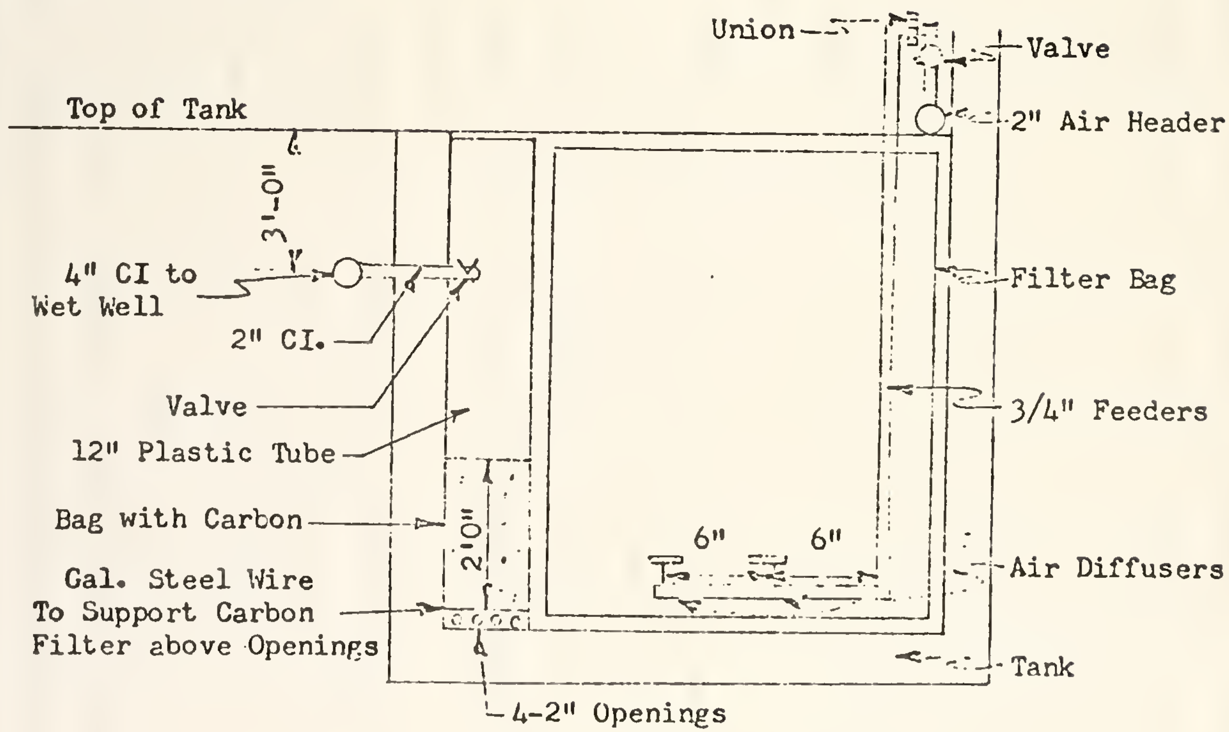
Details of Components Unique to Once Through System

On the once through system serving north bound traffic, chlorination was provided. The chlorination contact chamber consisted of a 4 foot ID by a 5'-2 5/8" height cylinder. Effluent flowed to the chlorinator system through two 4 inch cast iron pipes, one from each tank. From the chlorinator, treated wastewater passed through an 8 inch pipe into the stream. A 1/3 H.P. circulating sump pump with attached and submerged ejector was used to eject chlorine from the chlorine tanks. A 42 inch baffle was placed in the center of the tank to promote chlorine contact. As mentioned previously, there was no chlorination at the recycle rest-stop.

Another fundamental difference on the once through system was that the effluent from the bags went out of the tank via two overflow pipes, each located at opposite ends of the tank. On the recycle system, the treated wastewater went out of the treatment tank, mostly by way of the 6 carbon contactors. These are described in more detail in the next section. Although two overflow pipes similar to those on the once through system were provided, only a small portion of the effluent escaped by this route. Thus, there was more opportunity for mixing of the treated wastewater between compartments on the once through system, since effluent from the bags in the middle of the tank had to flow through the other compartments to get to the effluent overflow pipes on the ends of the tank.

Detail of Components Unique to Recycle System

In addition to the nylon filter bag, an activated carbon system was installed in each compartment on the recycle system. The carbon units consisted of a standard 100 micron nylon bag, its material being the same as the nylon filter bag material. It was sewn into a 12 inch diameter by 24 inch length unit and there were draw strings at the top of each bag to prevent carbon granules from escaping. The bag was filled with activated carbon and placed inside of a 12 inch cylinder, 80 inches in length. This cylinder was bolted to the front part of the tank. Four 2 inch openings were drilled into the bottom of the plastic tube to allow treated wastewater to flow upward through the carbon contactor. The contactor itself was additionally supported on the bottom by a galvanized steel wire frame. The carbon originally used was a 12 by 40 mesh granulated activated lignite carbon known by the trade name of NUCHAR (West Vaco Corporation). A drawing of the bag and carbon contactor are shown in Figure 6.



Scale - None

NOTE - Effluent weirs placed at one foot below top of tank.

FIGURE 6. Setup of Compartment on Recycle Stystem.

Three feet from the top of the tank or two feet below the effluent pipe elevation, the water from the carbon contactor went directly into a two inch cast iron pipe. This two inch pipe had a valve in order to prevent backflow from the wet well in case a compartment had to be dewatered. The two inch cast iron pipe was connected to a 4 inch cast iron header pipe which eventually discharged into the wet well. The wet well, like the treatment tank, was recessed into the floor of the utility room. The wet well or holding tank was 5 feet in diameter by 7 feet in depth. When the water level was the same as the effluent overflow pipes, that is one foot below the top of the tank, the capacity of the sump was about 880 gallons. The sump was covered with a 1/2 inch thick cast iron plate.

Two automatic motor driven centrifugal pumps controlled by a duplex all electric constant pressure system were installed inside the wet well. Each pump (Model 1-1 1/2 NSB 12 7-1/2 Aurora Pumps, North Aurora, Illinois) was rated to deliver 100 gpm when operated against a total dynamic head of 105 feet.

Each pump was connected by a flexible coupling to a vertical ball bearing electrical motor with flanged bell end dowelled with motor support. Each motor was 7 1/2 H.P., 3 phase, 220 volt, 60 cycle, 1640 rpm, vertical hollow shaft squirrel-cage induction type, Nema frame, and 1.0 service factor with thermal protection against locked rotor and overload conditions. The motors were controlled by a duplex all electric constant pressure system. Both the constant pressure pumps and control unit were manufactured by Aurora Pump Company.

Water was pumped from the wet well into a surge tank (Model W X-204 Well-X-Trol), 16" in diam. by 64" high, having a 44 gal. capacity. Water was fed from this tank to the toilets.

Two additional components were added in the course of the research. One of the additions were two Cuno filters (AMF Model #3-A1-3) which were installed between the surge tank and the toilets. The Cunos is a cylinder, 6" in diam. and 35" long. The media is made of pressed felt with 50 micron pores. When the head loss built to about 40 psi, the cartridges were disposed and new ones put in. The second component was a carbon filter which was installed to replace the bags of activated carbon used in the design. This replacement was necessary because of excessive head loss caused by solids accumulated on the outside of the carbon bags. The activated carbon unit was a Culligan HR-42 containing 20 cu. ft. of carbon.

Basis for Sizing the System

The reststop facilities were sized on traffic counts made by the Indiana State Highway Commission. Traffic was projected to the year, 1990, and set at 21,240 vehicles/day (13). It is assumed this figure represents average daily traffic during August. Since a single reststop would serve traffic traveling in only one direction, each lane of I-65 was conservatively estimated to take an average daily traffic of 12,744 vehicles.

Of these 12,744 vehicles, composition was estimated at 13 percent trucks, 5 percent trailers, and 82 percent cars. The vehicles stopping to use the rest areas were estimated to be 15 percent of trucks, 15 percent of trailers, and 9 percent cars.

These estimates are partially based on two nationwide surveys in 1968 and 1969 published in reports compiled by the U.S. Department of Transportation, Federal Highway Administration (1). Based upon this information, it was concluded that each of the facilities should be designed for 1,285 vehicles.

It was assumed that each vehicle would have three occupants on the average and 75 percent of these people would use the restroom. Therefore, the restroom facilities were designed for 1,285 x .75 x 3 or 2,891 persons per day. Peak hourly use was estimated by multiplying the average number of users during the peak day by .135. Thus, it could be expected that 2,891 x .135 or 392 persons might use the facilities during a single hour.

A study was conducted to evaluate design parameters at Indiana State Highway rest areas as a prelude to implementation of the planning for the reststop reported on in this project (4). It was concluded that the design of the rest area sewage plant should be based on wastewater production of 5 gallons per capita per day and a BOD loading of .007 to .01 lbs BOD per capita per day. Based on this information, the treatment plant was designed for 2,891 x 5 equals 14,455 gallons per day or 392 x 5 equals 1,960 gallons per hour. Since 12 bags were used, this would correspond to a peak hourly loading to each bag of 163 gallons. This figure is based on the assumption that use of all the bags is homogeneous. At 3 gallons per flush from the commodes, this works out to about 54 flushes per hour.

In Phase 1 of the Purdue study on treatment of sanitary wastes at reststops (14), it was determined that hydraulic loading was the limiting or critical factor in the sizing of the filter bags. It was concluded in this report that a sustained filter rate of .004 gal per min per sq ft or 5.76 gal per day per sq ft was possible. This rate was found under conditions of pulse feeding, similar to those anticipated at reststops. This figure is probably quite conservative since Cho (11), in continuous flow studies on the filter bag, showed that a sustained rate of 13.5 gal per sq ft per day could be filtered at the expense of a 10 inch head loss. Pulse feeding was found to result in a higher filtering rate capacity than continuous feeding.

With 5.76 gal per day per sq ft as the design criteria for bag surface area, it was determined that 14,455 gpd/5.76 gpd per sq ft or 2,510 square feet of material was needed. It was decided to divide the loading from the 16 toilet and urinal fixtures into 12 bags of equal size that were 210 square feet each.

In the final design of the bag, which is shown in Figure 4, 5, and 6, the total surface area was about 227 sq ft, not including surface area on the bottom. Total volume was 272 gallons from bottom to top of the bag. This corresponds to 6.2 sq ft of bag surface area per cubic foot or .83 sq ft per gallon. This is not quite as efficient as Cho's bag where 6.8 sq ft of bag surface area per cubic foot was achieved (11). Total volume of each compartment from the bottom to the elevation of the effluent overflow pipe was 634 gallons. Total volume outside the bag was approximately 393 gallons.

If it is assumed that the level inside the filter bag ranged between the level of the effluent overflow pipe and the top of the bag, volume inside the bag varied between 235 and 272 gallons. At design loading, detention time will vary between 4.7 and 5.4 hours. If it is assumed that each user contributes .01 lb BOD per day, as was used in the design, the maximum expected BOD loading was 2,891 x .01 equals 28.91 lbs BOD per day. Divided equally among the 12 bags, this corresponds to a design BOD loading of between 66.2 and 76.7 lbs per 1000 cubic feet of aeration volume per day.

Since the surface area per cubic foot was similar in both Cho's system and the experimental bags used at the reststop, and idea of the scale up factor involved can be gotten by comparing the volumes of the experimental and prototype bags used at the reststop. Using the total volume of Cho's filter bag as 147 gallons (11) and the total volume of the bags at the reststop as 272 gallons, a scale up factor of 272/147 or 1.85 is the result. Therefore, there was not that much difference in size between the intitial lab unit and the experimental bags used in this research.

Air requirements were based upon Recommended Standards for Sewage Works (15) for extended aeration plants. Air supply was designed at 100 cfm per lb BOD per day. At a design BOD loading of 28.91 lbs per day, an air blower was designed to deliver 28.91 x 2000/1440 equals 40.15 cfm.

History of Plant

The prototype systems were designed by State Highway personnel with consultation from Purdue project personnel. When finally designed and approved by the Indiana Stream Pollution Control Board, they were put out for bids. As with any new and unique system, few bids were received and those that were, were above the engineers estimates.

Eventually on the third attempt at bidding a successful bidder was selected and awarded the contract. Cost for the Southbound recycle system was $38,000 and the Northbound non-recycle system $40,000. All-in-all, these costs were not greatly different from those of about $55,000 for similar facilities of conventional design at other reststops. Costs are highly related to the length of sewer lines and land area required both of which were minimal for these systems.

Start Up of Reactors

It has been shown that initial seeding of the bag reactor is necessary to build up a layer of solids on the fluffy material inside the bag before a high degree of treatment can be realized. The best way to do this has been to put activated sludge into them prior to actual use. Thickened waste activated sludge from the Lafayette, Indiana sewage treatment plant was used in initially seeding the reststop reactors used in this research. A tank truck with 1000 gallon capacity transferred the sludge. The truck was supplied through the courtesy of the City of West Lafayette.

Each bag received approximately 60 gallons of waste activated sludge with a solids content of about 1.5 and 2.0 percent. Sludge was drained from the truck into the bags through a two inch fire hose.

The once through system, men's side, was seeded on August 13, 1975. The women's side was not seeded at this time since it was suspected that there was a leak in the tank. On August 26, 1975, the women's side of the once through system was seeded and the men's side was reseeded. The reason that the men's side was reseeded was because no solids were observed inside the bags. However, this was probably due to the sludge adhering to the sides of the bags. On August 27, the recycle reststop was seeded with sludge. Effluent was recycled back into the toilets overnight so a solids layer would build up on the filter surface. The once through or Northbound reststop was opened to the public on August 28 and the recycling system on the Southbound lane was put into operation on September 2, 1975.

Operation of the Waste Treatment Plant

This interim report basically covers the operational experiences of the plant from September 1975 through the end of December 1977. At the end of March and the beginning of April, both rest parks had to be shut down sothat the bags could be repaired. Use by motorists ranged from moderate to very low with peaks during holiday weekends.

Appendix A shows a reevaluation of the design procedure used and an analysis of the actual water usage in the Northbound system from May 1976 through February 1977. When one applies a daily usage rate based on a load factor as is shown in the appendix, it is obvious that the design capacity of the system has been significantly exceeded on many days during this time period. With this type of data it is obvious that the system was being asked to do more than it could and as a result experienced problems beyond those anticipated. Unfortunately, this was not the only problem which plagued the systems. Numerous problems associated with its design and construction were discovered as the system was operated and thus, a major portion of the project effort has had to be devoted to solving and identifying these problems rather than to the operation and surveillance of the ability of the syst to treat wastewater.

The first problem encountered was that color was not being removed by the contactors on the recycle system. Therefore, a carbon contactor was constructed in the laboratory to determine possible cause of the failure to perform of the contactor units. These tests showed that the carbon was not as specified and so it was changed. After several experiences with clogging of the carbon bags, it was decided to install a carbon contact tank as previously described. This unit was backwashed, as needed, by drawing water from the sumps outside the filter bags and discharging into the center of th filter bags. Several initial backwash attempts were made using tap water, but the rate of demand exceeded the ability of the water supply pumps to deliver and so the sump was the only logical place to get the water. These initial backwashes also attempted to discharge the backwash water into the overflow tile field, which was too small for the purpose and the error was fortunately corrected prior to any damage to the tile field. The need for regular backwashes of the carbon unit was obviously the loss of biological solids through holes in the filter bags with the net result being that the carbon removed the solids much like any filter would do. Once the solids were coated on top of the carbon, not only did they cause headloss, they also anaerobically decomposed because of a lack of dissolved oxygen and in the process gave odor and a black color to the carbon unit effluent. Initially, the carbon unit did lose some carbon due to improper control of the backwash cycle (it was soon corrected), but later the apparent carbon loss was found to be black particles of biological solids from the anaerobic action on the top of the carbon bed. Eventually, the carbon unit had to be taken off-line because of the inability to keep it from serving as a filter and creating problems due to anaerobic action. It must be remembered that this was all eventually attributable to the inability of the filter bags to remain intack and thus, hold the biological solids needed to make the system function.

The second problem dealt with clogging of the flushometer valves on the plumbing fixtures of the recycle system. This invariably led to other troubles such as loss of water from the tank down the overflow pipe and possibly overflow of the bags. This problem did not appear until about mid October 1975 and did not get completely corrected until early February 1976 when the Cuno filters were put in.

The most serious problem encountered was holes being worn into the bags. This problem was suspected on the men's side of the once through system as early as the first part of October 1975 when gross amounts of solids were found in the effluent. This problem may have contributed to the trouble with the clogged flushometer valves in the recycle system. Since it was considered very difficult and expensive to pull each of the bags out of the tank and visually examine them, a major effort was directed towards indirectly analyzing which of the units were problem bags. As it turned out, all the bags had to be pulled out of the tanks in both rest stops because the contractor had not attached the cloth material to the frame according to specifications. As was learned later, the bags and the supports had to be removed on two other occasions during the period coverd by this report, each time the cause being holes worn in the material. It was finally diagnosed, through very careful detective type work, that it was the air issuing from the diffusers which caused the problems. The vibration caused by the diffusers was so severe that even when they were covered with a piece of nylon material cut from bags it was worn away and in shreds within a matter of a few days. These diffuseres were subsequently replaced by a plain drilled pipe system, which seems to have worked effectively.

There have been enumerable other minor problems which have plagued both system, but particularly the recycle system up through the end of December 1977. A combination of bag overflows due to high peak usage rates coupled with a too rapid opening of the system prior to the activated sludge seed being acclimated caused problems of ammonia accumulation. Had the activated sludge been more acclimated, it would have been able to oxidize the ammonia rather than having it accumulate to where it became toxic and caused system failure. Problems associated with sludge being pushed through the bags even when no holes were present because of the violence of agitation and the sludge on the outside of the bags going anaerobic and releasing ammonia compounded this problem. The Southbound reststop system was seeded six times during the period up to December 1977. Each time, with the exception of the last, the system was opened before acclimation had been achieved. The last time the system was closed, cleaned and seeded, a long enough acclimation period was allowed but an unexplained flooding of the system washed all of the acclimated seed out of the bags and caused a failure prior to even opening the unit to the public. There were two additional seedings of the Northbound reststop system after the initial seeding and these were a direct result of either bag holes or of total hydraulic overloading of the bags during peak usage which washed the solids out of the system. This problem of hydraulic overloading and the general deterioration of the bags and supports on the Northbound system has been a continual problem for over a year.

Routine Sampling and Analysis

From approximately mid September through mid November, sampling and analysis were carried out three times per week. From mid November until April sampling and analysis took place twice per week and then returned to the three time per week schedule.

On the once through system, samples were collected from the effluent pipes near the back part of the rest station. Since there were two effluent overflow pipes per tank, the overflow pipe towards the front, near the urinals, was plugged with an adjustable 4 inch soil plug. Thus, there was no need for compositing the samples in this system since effluent from all six bags went out one overflow pipe. During the latter half of January and the month of February, 1976, it was necessary to divide the men's treatment system into two separate systems for purposes of finding holes in bags. Therefore, both overflow effluent pipes were operative. Samples were taken only from that portion of the tank flowing into the overflow pipe near the back part of the rest station. This section of the tank included the last one to three bags, depending upon where the tank was divided.

Due to the nature of the recycle system whereby effluent went from the filter bag into a companion carbon contactor, a fixed volume composite was taken from each tank. An equal portion was taken outside each bag and composited in a gallon container. When the carbon contactors were removed later in the work samples were still taken in the tubes where the contactors had been.

In addition to this, samples were taken inside of each bag on both the recycle and once through system. All of the samples were taken to the Environmental Engineering Laboratories at Purdue University and were either analyzed the same day or put into a refrigerator to be analyzed within the next day or two at the longest.

An accurate composite from the recycle system was difficult to obtain because of variable use of the toilets. The women's urinals and the commodes for the handicapped were used infrequently, according to rest-stop attendants. There was no way to get a relative estimate of toilet use. Many times, scum on the surface of the tank would seriously interfere with sampling and make the effluent look much worse than it actually was. A sampler, consisting of a pint container attached to a 4 foot metal rod, was used in gathering and compiling samples. The sampler was submerged about 6 inches below the water surface. If scum or floating sludge was visible, this was skimmed off as well as possible before the sample was taken. Many times it was difficult to get all the floating material skimmed off the surface since skimming tended to agitate or mix some of the sludge with the treated wastewater.

On the other hand, it is possible that solids, which got to the outside of the bag, settled out and effluent SS may have been much lower than actually was the case. It was later shown that this was the case.

Since sewage was discharged directly from each fixture into the bag, it was impossible to get an influent or raw wastewater sample. However, there is sufficient data from reststops to indicate the general characteristics of sewage. These are the only basis for determining efficiency of the sewage treatment plants at the reststop.

Effluent was analyzed on both once through and recycle systems for ammonia nitrogen, nitrate nitrogen, soluble ortho phosphate, BOD, COD, and SS. Additional tests on the recycle system effluent included total solids, total volatile solids, and color of water. Tests inside the bags included dissolved oxygen, pH, MLSS, and MLVSS. DO's were analyzed in the field while all other tests were performed in the lab. The terms BOD and COD mean biochemical oxygen demand (a measure of the oxygen pollution potential on a stream or body of water) and chemical oxygen demand (a short cut approximation of the BOD test), respectively. The abbreviation SS refers to suspended solids, which is the non-dissolved matter in a water or wastewater. Since the operation of both systems depends on biological action of flocculated microorganisms for their success, the need to measure the level of them is essential. The name applied to the microorganisms in the process is mixed liquor suspended solids, MLSS. An attempt to measure the viable vs. the dead microorganism population in the MLSS is by combustion at 600°C and so the term MLVSS for mixed liquor volatile suspended solids is coined. Lastly, the abbreviation DO is commonly used and refers to dissolved oxygen, which is the key to the whole of the biological process. The pH or hydrogen ion concentration is of importance to measure to assure that it stays within the region for microorganism growth, which is usually considered to be 5-9. Nitrogen measurements, and specifically ammonia nitrogen, is important both as a source of nutrient and as a demand for oxygen since it is eventually converted to nitrate in a well operating process.

All analyses, except color, were carried out according to procedures given in <u>Standard Methods</u> (16). Sample pH's were measured electrometrically using a pH meter (Leeds and Nothrup Co.). Prior to measuring the pH, the meter was standardized to pH 7.0 with a pH 7 buffer solution (Sargen-Welch Scientific Co.).

Whatman No. 40, 90 mm filter papers were used to determine suspended solids concentration in effluent samples. Sample size ranged from 300 to

1000 ml, depending upon how much could be gotten through the filter.

Whatman No. 1, 90 mm filter papers were used to determine the MLSS inside the bags. Sample size varied from 100 to 500 ml. To determine MLVSS, both the clean filter paper and aluminum foil tare were weighted as a unit. Then, the filter paper was tared separately. After the used filter paper had been in a 600^{o}C muffle furnace and cooled in a desicator, the tin with the ash was weighed. Nonvolatiles were figured on the basis of the difference between the tin foil by itself and the tin foil with the ash. An additional subtraction of .3 mg was made from the non-volatile portion to correct for the ash present from the burned filter paper. In most cases, the contribution of ash from the filter paper was negligible.

Dissolved oxygen was measured inside the bags and in the BOD bottles with a Galvanic Cell Oxygen Analyzer (Precision Scientific Company, Chicago, Illinois). Dissolved oxygen inside the bags was measured on site. The oxygen meter was first standardized by waving the probe through the air and then ajusting the meter to the proper DO based on the temperature of the air.

An oxygen analyzer specifically made to be inserted into BOD bottles was used to determine DO in the BOD bottles. The meter was calibrated by using the azide modification of the dissolved oxygen test in Standard Methods (16). The calibration was accomplished by first filling three BOD bottles with DI water which had been allowed to stand at least overnight in a 1000 ml graduated cylinder. The dissolved oxygen test in Standard Methods was then used in determining the DO of two of these bottles. The probe was inserted into the third bottle and the meter was adjusted accordingly.

In the measurement of nitrates and phosphates, the Hach Kit (Hach Chemical Company, Ames, Iowa) was used. The nitrate test was in accordance with the Cadmium Reduction Method while the ortho phosphate test was based on the Ascorbic Acid Method, both methods being part of Standard Methods. It was felt that the Hach Kit was adequate for relative measurement and also was accurate enough for the purpose intended. In measuring nitrates, it was found that the brown color of the water in the recycled system interfered in being able to zero the meter. Therefore, about 200 to 300 ml of sample was mixed with activated carbon. The sample was then filtered through Whatman No 1 filter paper. From the standpoint of convenience, both phosphates and nitrates measurements were made on the filtrate. If there was sufficient color in the once through effluent samples, the above procedure was applied to these also. Otherwise ortho phosphates and nitrates were run on the settled effluent samples. In measuring ortho phosphates, a dilution ratio of as much as 30 to 1 had to be made. Even for nitrates, a dilution ratio of at least 20 to 1 was necessary periodically. Procedure used was according to that given in the Hach Kit Manual (17).

The Hach Kit meter and slide were also used to measure color. The purpose of measuring color was to determine when the carbon contactors were beginning to fail. Therefore, the actual color units in the effluent from the recycled system were less important than the measured day to day changes. Color was measured on the settled effluent from the recycle system. The Hach Kit meter was standardized by zeroing the meter with DI water. The samples were then inserted into the meter and the corresponding color units were read. In some cases, the sample had to be diluted to about 1 part sample to 1 part DI water.

Water meter readings were also part of the routine sampling and analysis work at the reststops. The water meter at the recycle system only recorded water pumped from the well. Thus, the only water recorded here was used for drinking, washing hands, and cleaning. It was assumed that water use at the once through system accurately reflected conditions at the recycle side. Therefore, by comparing the differences in water meter readings, one could get an idea of how much water can be saved by recycling.

Water meter readings were taken by Purdue researchers every time samples for analysis from the reststop was obtained. The State Highway Commission began keeping daily records on the once through system on January 23, 1976.

Water usage figures should reflect actual consumption on the once through system. However, on the recycle system, meter readings may be inflated from actual water used by visitors, especially during mid October 1975 to the first week in February 1976. This was the period when there was considerable problems with the flushometer valves. Also, at times the attendants put in so much makeup water that often the effluent would be going over the effluent overflow pipes.

Color Removal Testing Apparatus

Previous to making studies on the existing carbon in the rest stop carbon contactors, effluent was put through a millipore filter apparatus and visual evidence of color removal noted. After it was determined that there was significant removal by the millipore filter, a carbon contactor apparatus was constructed in the lab to actually test the carbon used at the rest stop. The apparatus used consisted of a one inch glass column, approximately 4 feet long. Inside diameter was about 2.28 cm. The column was packed with about 3 feet of carbon. The bottom was supported by a rubber stopper which had been stuck in the end and puttied to the glass column to make an air tight seal. Since the rubber stopper had a hole in it to allow water out of the column, a piece of nylon cloth was placed inside the column to prevent carbon particles from going out of the contactor.

Treated wastewater from the recycled system was fed to the unit by gravity through one quarter inch tygon tubing. The influent reservoir consisted of a 20 liter polyethylene bottle located about 4 to 5 feet above the top of the carbon column. The tygon tubing was tied into a rubber stopper at the top of the column in such a way that an air tight seal was accomplished.

Water escaped from the bottom of the column through a short piece of one quarter inch tygon tubing. Rate of flow was controlled by an adjustable clamp attached to this tygon tubing. Figure 7 shows the diagram of the carbon contactor apparatus.

The column was first put into operation by allowing clean water to flow up through the carbon to expell the air. Then the colored sample from the reststop was put through the carbon from the top. At least one bed volume was wasted in order to get the clean water out and the sample was then allowed to filter through the column into the collection reservoir. Periodically, samples were taken from the end of the contactor for color analysis. The collection reservoir was calibrated so that the volume per unit time could be measured through the column.

Color was measured on both the treated wastewater fed into the unit and the effluent samples from the lab scale contactor. The Spectronic 20 (Bausch and Lomb) was used to determine the efficiency of the carbon absorption unit. A wavelength was selected where maximum light absorption took place in the wastewater samples. This wavelength turned out to be 325 Angstroms. The Spectronic 20 was standardized by adjusting the meter to zero percent absorbance for DI water and 100 percent absorbance with complete darkness inside the sample holder. The instrument was standardized in this way after each sample was analyzed.

During the adsorption tests, it was determined that the wrong carbon had been used in the reststop. Adsorption tests were then run on Culligan Water Co. Type Cullar D 12 x 40 mesh activated lignite carbon. The same

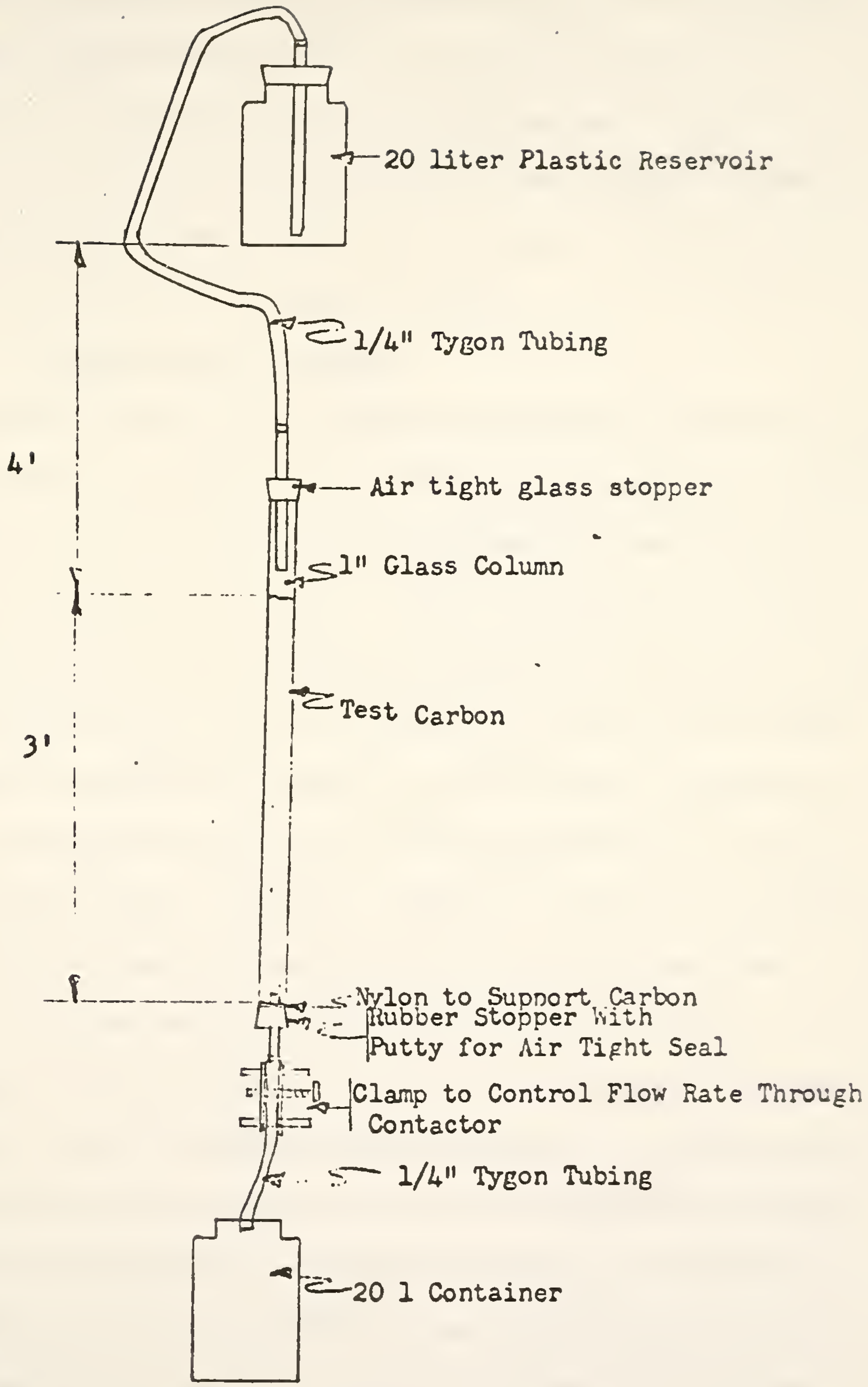


FIGURE 7. Experimental Apparatus For Testing Carbon.

experimental apparatus as that specified above was used. However, color was measured with the Hach Kit using the procedure spelled out under the section on "Routine Sampling and Analysis". The basis of analysis in both color tests was to determine when color breakthrough or carbon failure would occur. Thus, it was really not necessary to use the same testing procedure on both types of carbon. No attempt was made to try to relate the results from the two types of carbon.

Finding Holes in the Bags

It was suspected as early as the first part of October 1975 that there were holes in the bags on the men's side of the once through system. Therefore, a major part of the first part of this project concerned itself with trying to identify which bags had holes. A 7½ H.P. Gorman Rupp trash pump was used to pump down the levels outside the bags and at the same time clean up some of the sludge on the bottom of the tanks. As much of the contents outside the tanks as possible was pumped into adjacent bags. The reason for the pumping was basically two fold. If there were holes in the bag, these could possibly be seen. Secondly, it might be possible to determine which bags had holes in them by observing the rate at which the level inside the bag fell as the water outside the bag was being pumped.

On the recycle system, the pump tests were combined with SS analysis outside the bags. Several assumptions had to be made in interpreting the data. It was assumed that the pumping, which had been performed several days previous to the SS analysis, had removed the sludge and scum which could have interfered with the analysis. It was further assumed that a leak in one bag would not affect the quality of effluent in an adjacent bag, since each carbon contactor outside the bag essentially served the purpose of an effluent weir. Therefore, any appreciable SS outside of a single filter bag could indicate holes in that unit.

These assumptions certainly are questionable first of all due to the difficulty of being able to effectively clean all the sludge from outside the bag by pumping. Second of all, there was ample opportunity for flow between adjacent bag units. It cannot really be said how much actual mixing there was, however.

On the once through system, only one bag could be analyzed at a time with the testing procedure adopted. The flow from the bags upstream from the bag being tested was diverted to the overflow pipe at the other end of the tank. Two one liter/min pumps (Chem-O-Feeder Chemical Pumps, BIF Industries, Providence, Rhode Island) were used to recycle effluent from outside the bag back into it. Water was recycled from near the bottom of the tank by one pump and from near the top by the second pump. Samples were taken from the discharges of the pumps at the beginning and end of the test run, which lasted at least one full day. If there was an improvement in effluent quality after the test run, it was assumed that the bag may be working properly. If there was little or no improvement, the bag was suspected of having holes.

Twenty liters of concentrated activated sludge from the Lafayette, Indiana sludge thickener was placed in one of the bags, the effluent was recycled, and the analysis performed according to the procedure cited above. In addition, a sample was grabbed inside the test bag 20 minutes after the sludge had been placed inside the bag. It was assumed that by this time, the sludge would be thoroughly mixed inside the bag. In this experiment, it was also assumed that if the solids level increased outside the bag and decreased inside the bag, there was significant cause to believe that there were holes in this bag.

This method of recycling the effluent with the chemical pumps would be a good way to find leaks if it could be assumed that most of the water outside the bag could be recycled. However, it is rather doubtful that any effluent, other than from the front part of the bag where the pump suction lines were, was actually being recycled. Due to the nature of the system, the only way of getting good recycling of all the effluent into the bag would have been to put multiple suction tubes around the outside of the bag and this would have run into too many complications.

Other tests, probably less reliable than the ones mentioned, were also made on the once through system. These consisted of analyzing for SS outside of each of the bags. SS were first run in about December, before the trash pump was used to pump from outside the bags. Suspended solids were again run 8 days and 14 days after pumping outside the bags with the large trash pump. Of course, there was more chance of effluent from one bag affecting the SS results from other bags in comparison to the recycle system.

It should be noted that all the tests described are approximate or qualitative. However, they were the only ones which could be devised short of actually taking the bags out of the tanks and examining them. Pulling all of the bags out of the tanks was considered to be too expensive and the risk involved in damaging them too great. However, since the contractor had not followed specifications on tying the bags to the supporting frames, all the bags had to be pulled anyway and this culminated this portion of the project. The procedure of pulling all of the bags from the tank compartments to repair holes was also done again on the recycle system during Sept. and Oct. of 1977.

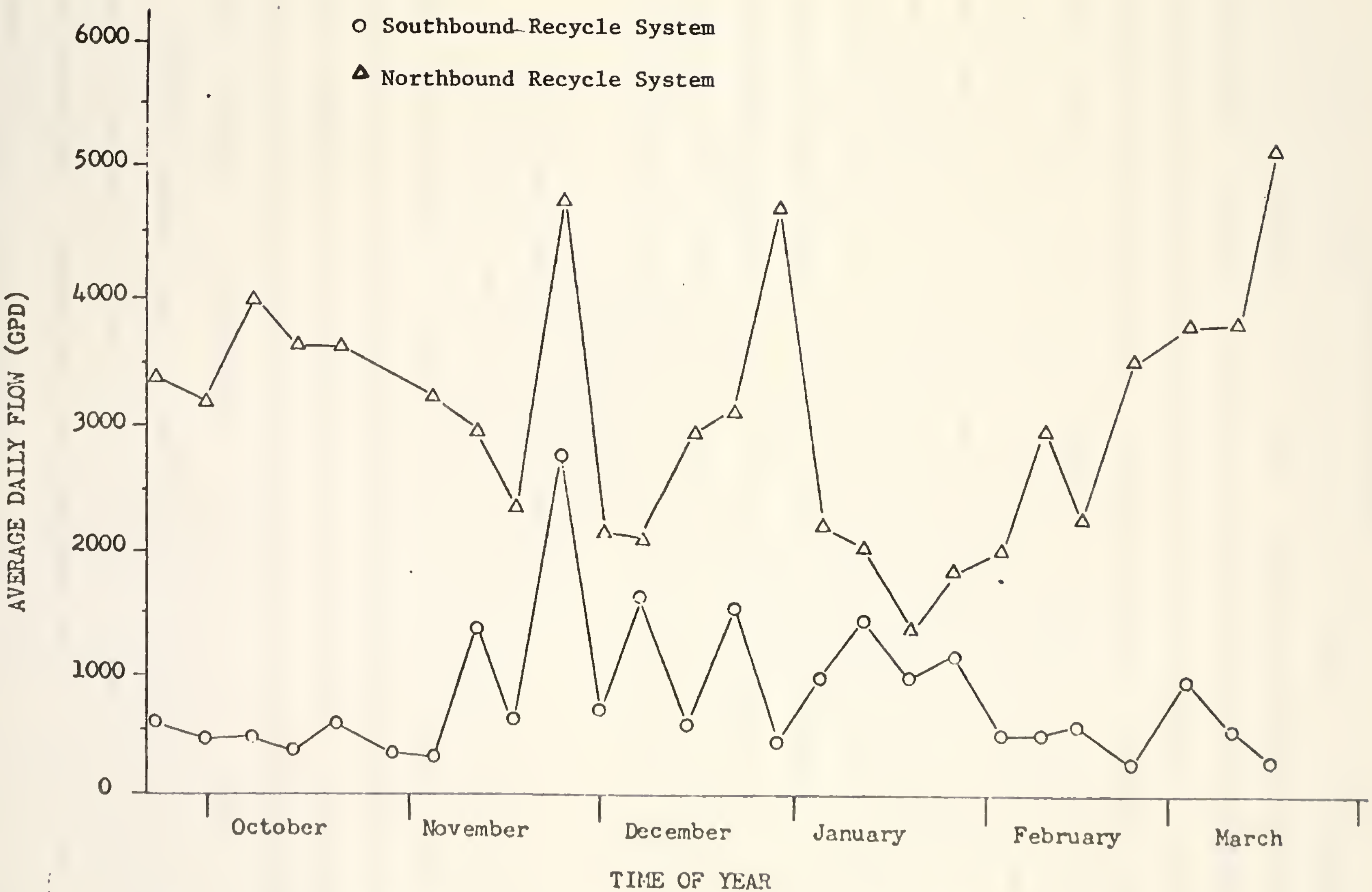


FIGURE 8. Weekly water Usage on Once Through and Recycle Systems.

Results and Discussion

From the opening of the two systems to the public in early September 1975 to the end of the first week in January 1976, the reststops functioned but by the week of January 12, problems with solids loss outside the bags became so severe that both North and Southbound system were closed. This shutdown lasted 22 days, during which the contractor repaired the bags and completed tying the bags to the wire mesh supports as originally required. Another shutdown for 20 days took place in April for the same purpose of repairing the holes which were abraded in many of the bags. No other shutdowns of any significance occurred in 1976 except for five days in November for installation of the activated carbon filter in the Southbound system. The recycle system was again closed for repair of bags and system reseeding as well as thorough sump cleaning for about 10 days each time in March, July, and September 1977. The non-recycle system has not been closed although much of the time its functioning has been less than desirable since April 1976.

Routine Analysis

Public Use of Reststop - Water Consumption

Table 2 gives a monthly account of water use both at the once through and recycle reststops. Average water use at the once through system over the period from the end of September 1975 through February 1976 was 3,140 gpd. Water consumed at the recycle reststop was only 736 gpd. If it is assumed that as many people use the recycle restrooms as the once through north bound restrooms, the water saved by recycling was about 77 percent.

This 77 percent figure includes a period of time where the recycle system was not functioning very well and much of the recycled water was lost from the system due to problems with the flushometer valves. This is why the water saved by recycling was much greater, as shown in Table 2, for the months of September, October, February, and March, a time when stuck flushometer valves were not a serious problem. During the months from November through January, stuck flushometer valves were a serious problem and this is why water consumption fluctuated so much on the recycled system, as shown in Figure 8.

A more realistic water savings estimate from recycling was made by examining nearly two months of data and it showed about an 87% savings. Even during these four months, conditions at the rest stop probably were not optimal and this 87 percent figure may be low.

Characteristics of Aerated Liquor Inside Bag Reactors

Tables 3 through 6 give a summary of the analytical data inside and outside of the bags at both rest stops. Table 3 presents data showing the difference between the treatment units serving the men's and women's sides of the rest stop. In most cases, these data clearly show that the loading on the women's side of the system was very low compared to that on the men's side. The data also clearly illustrate that the loss of MLSS by overflow or by passage through the bags was the major contributor to the failure of the system to produce an acceptable quality effluent. Tables 5 and 6 show the corresponding data for the recycle system. These data show very clearly that if the concentration of mixed liquor solids decreased,the concentration of ammonia increased and the system at that point failed to function and thus necessitated the closing of the rest stop. In the case of the recycle system, there were a significant number of closures, the reason for which was previously pointed out. At one point, acidification was used to control the ammonical odors, but since this was only a symptomatic treatment rather than a basic corrective measure it too failed to control the problem. During the first week of July 1977, low water use toilets were installed in the southbound rest stop and they drastically cut the water use to an extent that no hydraulic problems at all were encountered after their installation.

The most significant operating parameter found during the operation of the recycle system was that of placing nothing but urinal wastes into a bag. Under no circumstances could a population of microorganisms be established and maintained in these bags. It is therefore one of the objectives in modifying the rest stop to change this around so that the wastes from the urinals is uniformly distributed to all bags.

Also shown in Tables 3 through 6 are the data relating to the effluent from the once through system (Tables 3 and 4) and the quality of the recycle water in the southbound system (Tables 5 and 6). It can be seen from these data that there were only relatively brief periods when the effluent from the system could meet the levels for BOD and suspended solids required by the NPDES permit for the non-recycle system. In almost every case, a careful analysis of the data shows that it was not the inability of the system to remove the BOD but a problem with hydraulic overflow or leaks through holes in the bag which caused the system to be out of compliance. The data in the tables are very similar to that determined on routine samples collected and analyzed by personnel of the Indiana State Board of Health, and also to that gotten by the State Highway people on their sample analysis.

The last column depicts the overall average of MLSS based on the six bags on the designated side and system. Maximum and minimum values and standard deviation refer to the maximum, minimum, and standard deviation of the average MLSS in the six bags recorded for each analysis made. In computing these values, if an entry was missing for a certain bag and date, this missing entry was assumed to be the monthly average MLSS value for that bag. The MLVSS is a weighted average of the average MLVSS values shown for each bag.

Summary

Difficulties in going from a prototype to a full scale system which are usually experienced during scale up were definitely the major portion of the problems encountered during the period of this project covered by this report. As was previously pointed out, almost the total efforts of the people concerned with the project had to be devoted to correcting mechanical, physical or hydraulic problems leaving essentially no time to work on perfecting the operational control of the system. When the fact that the short duration high intensity use periods experienced by the system far exceeded its capacity, it is understandable why it was impossible to keep the liquid from overflowing the top of the bags. This overflow in the case of the once through system was almost continual during peak usage and thus caused NPDES permit violations. In the case of the recycle system, the overflow allowed solids to accumulate outside the bag where they then anaerobically decomposed releasing ammonia and thus caused a progressive failure because of the toxicity of high ammonia levels to the aerobic organisms inside the bags.

There were several problems of a design nature that were encountered during the period of the project covered by this report. One oversight was the lack of control valves on the air supply which was corrected prior to operation of the systems. Another was the lack of filters to prevent flush-o-meter valves from clogging which was corrected by installation of cartridge filters. Use of cloth bags to hold the decolorizing activated carbon proved unacceptable because of headloss due to solids accumulation, but a carbon filter unit also proved unacceptable for the same reason, that of solids accumulation. The major problem to date has been the need for an effective bag support means that won't cause abrasion holes in the nylon material and allow the biological solids to be uncontained. Other problems such as ventilation of a more adequate capacity in the treatment room and a means to split the load between the men's and women's sides of the restrooms are needed and will be accomplished on a modification of the existing facilities at some later date. A means for bag removal, if bags are ever used again, is essential as is the need for getting better distribution of feces and urine to all bags instead of using some bags for urinals alone and the split between men's and women's usage was never known or allowed for, so unequal loads developed. Hydraulic peak loads as shown in Appendix B were also much greater than ever expected and when added to the split between men and women usage, were extremely important as far as system storage for short time periods were concerned.

In spite of the numerous difficulties and the oversights in materials selection, construction practices, and oversights in design, it is still worthy to continue the research because of the promise which the system holds both in effluent quality and in water savings when it is made to function properly. The fact that commercial systems based on this very same design are now functioning is at least proof that the concept is correct and the system is capable of working full scale just as it did in the prototype laboratory system.

TABLE 2

Water Use - Once Through and Recycle Systems

		Once Through GPD	Recycle GPD	% Water Savings in Recycled System
	Ave	3340	230	93.1
Sept 75	Max	4580	244	
(1 week)	Min	1680	190	
	Ave	3550	410	88.5
Oct 75	Max	5260	860	
	Min	2770	245	
	Ave	3270	1190	63.4
Nov 75	Max	6700	3600	
	Min	1910	115	
	Ave	2650	1020	61.5
Dec 75	Max	3540	2410	
	Min	1480	510	
	Ave	2380	987	58.5
Jan 76	Max	5700	1730	
	Min	1010	300	
	Ave	2400	480	80.0
Feb 76	Max	3860	720	
	Min	1360	260	
	Ave	4480	441	90.2
March 76	Max	5900	971	
	Min	3520	197	

Ave = 3140 gpd - Once through
Ave = 736 gpd - Recycle

77% Savings in water overall by recycling
Data from nearly two years shows an 87% saving by the recycle system.

Table 3
Interstate Rest Area Wastewater Treatment
Non-recycle System
Northbound Lanes

Date	Side	SS	NH_3^-N	COD	BOD	MLSS	PO_4	NO_2^-N	Flow	pH
Sept.75	Men	17	70	113	1	457	13	6	3340	7.8
	Wom.	3	1	55	7	317	11	22		7.6
Oct. 75	Men	292	54	263	53	583	27	3	3550	7.8
	Wom.	4	3	28	5	809	18	18		7.6
Nov. 75	Men	172	39	331	93	199	32	3	3270	7.7
	Wom.	2	8	29	5	551	21	26		7.7
Dec. 75	Men	144	46	280	71	129	23	2	2650	7.5
	Wom.	3	6	29	7	653	14	38		7.6
Jan. 76	Men	120	54	342	70	132	49	4	2380	7.6
	Wom.	113	9	76	38	300	33	23		7.6
Feb. 76	Men	114	32	331	53	194	44	4	2400	7.5
	Wom.	49	4	128	29	148	22	17		7.6
Mar. 76	Men	63	53	231	134	1168	22	4	4480	7.6
	Wom.	23	16	71	51	121	28	14		7.7
Apr. 76	Men	25	76	136	70	68	22	7	3750	7.8
	Wom.	18	27	96	62	192	13	2		7.7
May 76	Men	25	99	218	76	1089	31	5	7970	7.7
	Wom.	78	40	159	77	252	13	6		7.6
Jun. 76	Men	63	78	170	122	1938	16	1	7345	7.4
	Wom.	106	37	221	106	422	9	2		7.7
Jly. 76	Men	383	90	467	242	932	23	4	8407	7.5
	Wom.	79	42	220	111	615	15	2		7.4
Aug. 76	Men	134	67	252	157	3360	28	8	7189	7.4
	Wom.	185	26	164	93	2647	11	8		7.6
Sept.76	Men	123	87	182	114	5579	23	7	4057	7.4
	Wom.	35	19	95	58	1613	10	10		7.4

Table 4
Interstate Rest Area Wastewater Treatment
Non-recycle System
Northbound Lanes

Date	SS	NH_3-N	COD	BOD	MLSS	FLOW	pH
Oct. 76	47	50	115	63	3871	3650	7.4
Nov. 76	66	37	117	66	3733	3060	7.4
Dec. 76	24	37	67	46	3400	2550	7.5
Jan. 77	34	30	72	38	3270	2340	7.5
Feb. 77	73	29	82	39	2490	——	7.6
Mar. 77	61	40	74	40	2410	3010	7.5
Apr. 77	50	48	129	59	2370	4760	7.5
May 77	114	59	148	97	1105	6630	7.9
Jun. 77	273	60	354	172	1630	10270	7.8
Jly. 77	34	44	135	76	1530	21750	8.0
Aug. 77	72	38	156	95	1305	12570	7.8
Sept.77	23	40	141	50	1550	8310	7.8
Oct. 77	58	41	120	41	1520	——	7.8
Nov. 77	29	32	102	25	1560	——	7.6
Dec. 77	25	47	70	22	1750	5810	7.5

Table 5
Interstate Rest Area Wastewater Treatment
Recycle System
Southbound Lanes

Date	Side	SS mg/l	NH_3-N mg/l	COD mg/l	BOD mg/l	MLSS mg/l	PO_4 mg/l	NO_3-N mg/l	Flow gal/day	pH
Sept.75	Men	19	164	241	17	115	13	22	230	8.
	Wom.	10	147	209	32	154	10	26		8.
Oct. 75	Men	31	194	238	41	466	37	52	410	8.
	Wom.	9	192	205	39	311	36	52		8.
Nov. 75	Men	106	67	285	57	487	46	42	1190	7.
	Wom.	8	61	151	32	743	40	49		7.
Dec. 75	Men	36	71	130	31	128	18	22	1020	7.
	Wom.	29	62	107	50	587	23	43		7.
Jan. 76	Men	48	122	170	38	190	32	22	987	7.
	Wom.	12	97	164	75	677	33	94		7.
Feb. 76	Men	43	71	206	24	280	39	29	480	7.
	Wom.	14	24	103	20	625	39	62		7.
Mar. 76	Men	77	59	249	113	756	52	45	441	7.
	Wom.	25	46	167	52	784	58	80		7.
Apr. 76	Men	44	208	238	114	705	22	23	927	7.
	Wom.	72	157	278	121	282	30	26		7.
May 76	Men	98	188	254	91	732	29	16	601	7.
	Wom.	30	133	214	57	964	47	63		7.
Jun. 76	Men	65	333	315	143	576	44	8	961	8.
	Wom.	77	245	299	170	267	59	19		8.
Jly. 76	Men	98	448	460	227	493	49	4	937	8.
	Wom.	96	364	539	215	213	61	8		8.
Aug. 76	Men	122	668	610	247	573	44	6	438	8.
	Wom.	86	603	499	234	157	47	7		8.
Sept.76	Men	16	99	109	30	1118	49	21	932	7.
	Wom.	9	54	90	21	485	44	32		7.

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Table 6
Interstate Rest Area Wastewater Treatment
Recycle System
Southbound Lanes

Date	SS mg/l	NH_3-N mg/l	COD mg/l	BOD mg/l	MLSS mg/l	FLOW gal/day	pH
Oct. 76	72	245	235	106	340	890	7.8
Nov. 76	162	64	77	60	1520	270	7.4
Dec. 76	37	135	123	48	920	470	7.5
Jan. 77	62	234	200	68	570	210	8.0
Feb. 77	67	307	242	51	1145	—	7.8
Mar. 77	REST STOP CLOSED						
Apr. 77	86	108	210	131	2970	240	7.2
May 77	550	176	376	201	430	—	8.0
Jun. 77	407	414	377	210	270	300	8.2
Jly. 77	REST STOP CLOSED						
Aug. 77	113	319	511	249	1580	460.	8.1
Sept.77	REST STOP CLOSED						
Oct. 77	324	250	230	72	2110	—	8.2
Nov. 77	215	403	705	385	170	—	8.4

Appendix A

Original Design

1990 ADT 21,240

ADT Directional 0.6 x 21,240 = 12,744

Total vehicle stops per day	1285
trucks	249
trailers	96
cars	940
Peak hour vehicle stops	174
trucks	34
trailers	13
cars	127

Water usage: 7.7 gal/vehicle stopping

Persons/vehicle: 3, 75% of which use facilities

1285 vehicles x 3 x 0.75 = 2891 persons/day use facilities

Water used per day

1285 vehicles x 7.7 gal/vehicle = 9894.5 gal/day

Water used at peak hour

174 vehicles x 7.7 gal/vehicle = 1339.8 gal/hr

Water use/person who uses facilities

7.7 ÷ 3 x 0.75 = 3.42 gal/person/use

Design for bag system

5 gal/person/use

2891 people x 5 gal/person/use = 14,455 gal/day

Since this was 1.46 times original design capacity no further allowance was made for max. day over average day.

Peak hour water usage

The 1339.8 gal. figure could be used or a figure of 174 x 3 x 0.75 x 5 = 1957 gal could be used.

The 1957 figure based on the already 1.46 factor seemed excessive.

Another approach was to use the fact that one toilet flush is the same as two urinal flushes. If it is assumed that each toilet or each two urinals are used every 3 minutes, the load would be:

4 toilets + 2 equiv. toilets (4 urinals) x 20 uses/hr x
5 gal/use x 2 sides of rest stop = 1200 gal for peak hour.

Thus, 1200 gal. was used.

1200 - (14,455 ÷ 24) = 600 gal over normal capacity.

600 gal ÷ 12 bags = 50 gal/bag for storage

This gave free board of 12 inches plus for one hour bags could really operate at twice design capacity.

If the system had been designed by FHWA guideline (which wasn't available until after design was completed and under construction) the following would have resulted:

.09 ADT x 5.75 (ave)

.09 ADT x 7.00 (max)

1990

21,240 x 0.6 x 0.09 = 1147 vehicles/day entering rest area and using it.
1285 used for our design

21,240 x 0.6 x 0.09 x 5.75 = 6595 gal/day

21,240 x 0.6 x 0.09 x 7.00 = 8029 gal/day
9894.5 gal used for our design later

increased to 14455 gal/day

Overall conclusions:

ADT data very much in doubt for 1990

1975 data for weekday showed 18,575

1976 estimate 19,875

Split between men and women usage totally overlooked

Peak usage factor not nearly compensated for in 1990 and especially not at present.

Appendix B

Table 1
Actual Water Usage Northbound
May 76 thru Feb. 77

May gal.	June gal.	July gal.	Aug. gal.	Sept. gal.	Oct. gal.	Nov. gal.	Dec. gal.	Jan. gal.	Feb. gal.	
6390	11470	5460	8790	6710	4680	4660	1770	3890	560	1
5390	4960	8980	12050	14920	4780	2380	2670	5390		2
8550	5050	12550	7110	5300	5180	2360	2460	5920		3
4350	5290	10540	6370	9410	6600	2070	2840	2840	1620	4
3700	8520	8200	7430	9930	3730	2080	1740	2910	1830	5
3600	7070	12190	8320	7760	2550	3750	2800	2050	1360	6
3750	7390	8280	18170	13430	3840	4360	1320	2050	2050	7
3830	4800	6260	10970	7520	3550	3970	1060	6640	1020	8
5220	4860	8700	10990	7950	6180	2280	2090	2120	970	9
7050	4670	10050	7800	3810	4970	1680	1330	2170	2320	10
4020	6170	9830	7330	5170	7040	2010	2400	1200	1520	11
2920	9160		6040	4950	5010	3010	2610	670	2600	12
4000	8670		7420	7560	3240	3050	2130	1310	2680	13
3270	9050	32320	10450	3260	3200	2400	1680	1980	2510	14
4960	6600	4110	10690	2800	3240	4320	2580	140	1660	15
6340	4900	6330	10950	3390	6100	1730	2480	1340	2400	16
5060	5240	9590	7400	5730	4810	2050	2140	4300	1390	17
5420	7500	11390	5710	4770	5610	2910	3700	680	2060	18
3740	17950		7380	6010	4890	3080	3650	1000	3860	19
3210	8790		8210	6970	680	4770	3300	1520	2850	20
3580	11160	24210	10340	2890	2520	4240	3580	2000	3370	21
5910	7110	5210	20920	3750	3830		700	1350	2820	22
5760	4750	6460	11370	3310	4270		2830	2460	2390	23
6290	6010	9960	1060	2920	4000		4550	2050	2080	24
4090	7820	8970	6770	5680	5680		3160	650	2860	25
3610	9920		5820	4560	3240		2050	1830	3560	26
3690	10720		7750	5480	2070	2270	5550	1350	2560	27
5810	10190	22780	11300	3720	3290	3520	4750	snow	4660	28
7870	6200	6130	10710	2830	3710	3930	3310	snow	——	29
6250	5400	7720	11430	3360	3950	4180	4550	3430	——	30
10690	——	11550	6290	——		——		5300	——	31

Appendix B
Table 2
Number of Days in Which Actual Water Usage in Northbound
Reststop Exceeded a Given Number of Gallons/Day
May '76 thru Feb. '77

Number of Observations in Month

	31 May	30 June	25 July	31 Aug.	30 Sept.	31 Oct.	25 Nov.	30 Dec.	29 Jan.	26 Feb.
4000 gal and over	20	30	25	30	19	16	6	4	5	1
5000 gal and over	15	24	24	30	16	7	0	1	4	0
6000 gal and over	8	20	22	28	11	4	0	0	1	0
7000 gal and over	4	16	18	24	8	1	0	0	0	0
8000 gal and over	2	11	17	16	4	0	0	0	0	0
9000 gal and over	1	8	12	13	4	0	0	0	0	0
10000 gal and over	1	5	9	13	2	0	0	0	0	0
11000 gal and over	0	3	7	6	1	0	0	0	0	0
12000 gal and over	0	1	5	3	1	0	0	0	0	0
13000 gal and over	0	1	3	2	1	0	0	0	0	0
14000 gal and over	0	1	3	2	1	0	0	0	0	0
15000 gal and over	0	1	3	2	0	0	0	0	0	0

Appendix B
Table 3
Water Usage Rate on a Daily Rate for Maximum
Ten Hour Demand Period and Effect of the
Men's and Women's Usage on System Capacity

Actual Usage gal/day	Percentage of Usage Occurring in Max. 10 hr. Period 50% gal/day	60% gal/day	70% gal/day	80% gal/day
	50% Male and 50% Female Usage			
7000	8400	10080	11760	13440
8000	9600	11520	13440	15360
9000	10800	12960	15120	17280
10000	12000	14400	16800	19200
11000	13200	15840	18480	21120
12000	14400	17280	20160	23040
13000	15600	18720	21840	24960
14000	16800	20160	23520	26880
15000	18000	21600	25200	28800
16000	19200	23040	26880	30720
	60% Male - 40% Female Usage			
6000	4320	5184	6048	6912
7000	5040	6048	7056	8064
8000	5760	6912	8064	9216
9000	6480	7776	9072	10368
10000	7200	8640	10080	11520
	70% Male - 30% Female Usage			
5000	4200	5040	5880	6720
6000	5040	6048	7056	8064
7000	5880	7056	8232	9408
8000	6720	8064	9408	10752
	80% Male - 20% Female Usage			
4000	3840	4608	5376	6144
5000	4800	5760	6720	7680
6000	5760	6912	8064	9216
7000	6720	8064	9408	10752

Design capacity 7200 gal/day/men's or women's side of restrooms.

Line indicates system hydraulic capacity has been reached.

Explanation of Appendix B Table 3

Since the reststop systems can only handle a loading of 7200 gal in 24 hours on either the men's or women's side of the system, and since this is a rate, it is best to compare rates on a daily basis for short demand periods. A variable amount or percentage of use can take place during the demand period, and if unequal usage occurs on the men's or women's side, this further compounds the problem.

As an example, assuming the actual water usage on a day was 8000 gal in 24 hours but that 60% of this usage occurred in a 10 hour period. Thus

$$8000 \text{ gal} \times \frac{24 \text{ hr/day}}{10 \text{ hrs}} \times 0.60 = 11{,}520 \text{ gal/day}$$

would be the rate of loading on the system during that 10 hour period if 50% of usage was on the men's or women's side. If, however, 60% took place on the men's side, then 11,520 gal/day x 0.60 = 6912 gal/day would be the rate of loading on the men's side of the system during that 10 hour period.

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